

Interaction of Dust and Plasma on the Lunar Surface and in the Exosphere

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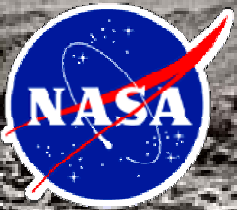
**Workshop on Science Associated with the
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UMBC



Berkeley
University of California

Motivation

Understanding the dust-plasma environment of the Moon.

During Apollo era horizon glow was seen at the lunar terminators.

Evidence that lunar surface charging drives electrostatic transport of dust ($< 10 \mu\text{m}$).

Fundamental Solar System processes also seen at Saturn's rings, asteroids (and Mercury?).

This environment could pose hazards to robotic and human exploration of the Moon.

Evidence for Dust Above the Lunar Surface

SURVEYOR-7
COMPOSITE

Horizon-Glow

Approximate
Position of
Solar Disk

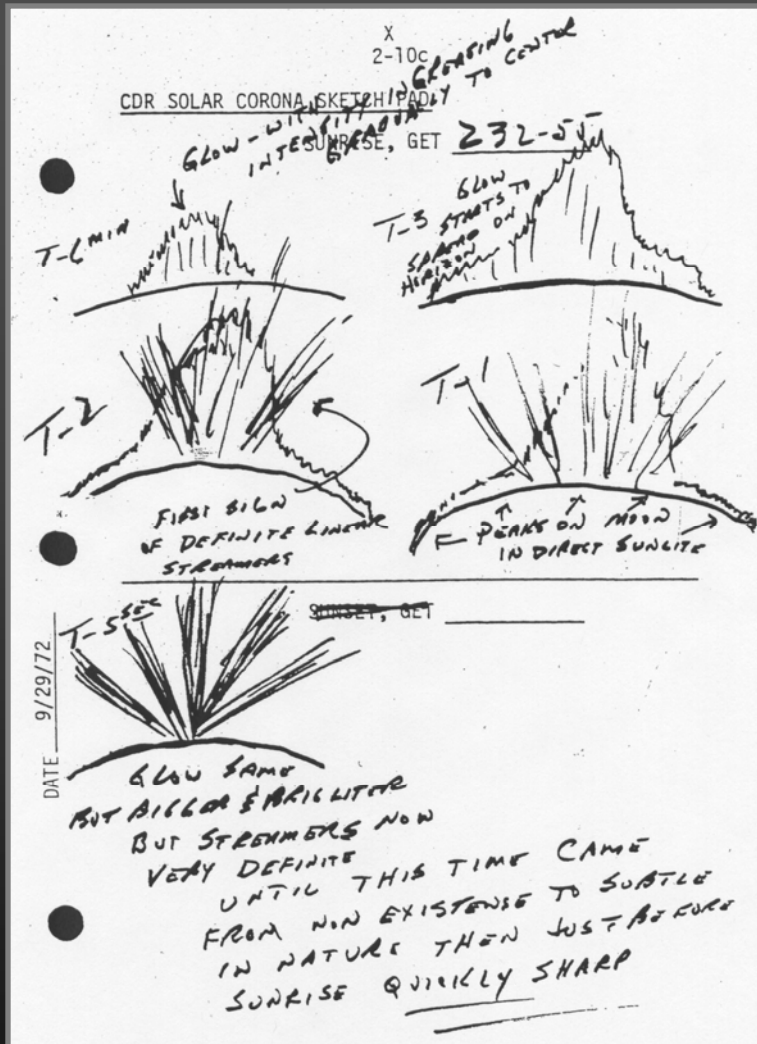
Horizon glow from forward scattered sunlight

- Dust grains with radius of 5 – 6 μm at about 10 to 30 cm from the surface, where electrostatic and gravitational forces balance.
- Horizon glow $\sim 10^7$ too bright to be explained by micro-meteoroid-generated ejecta [Zook et al., 1995].

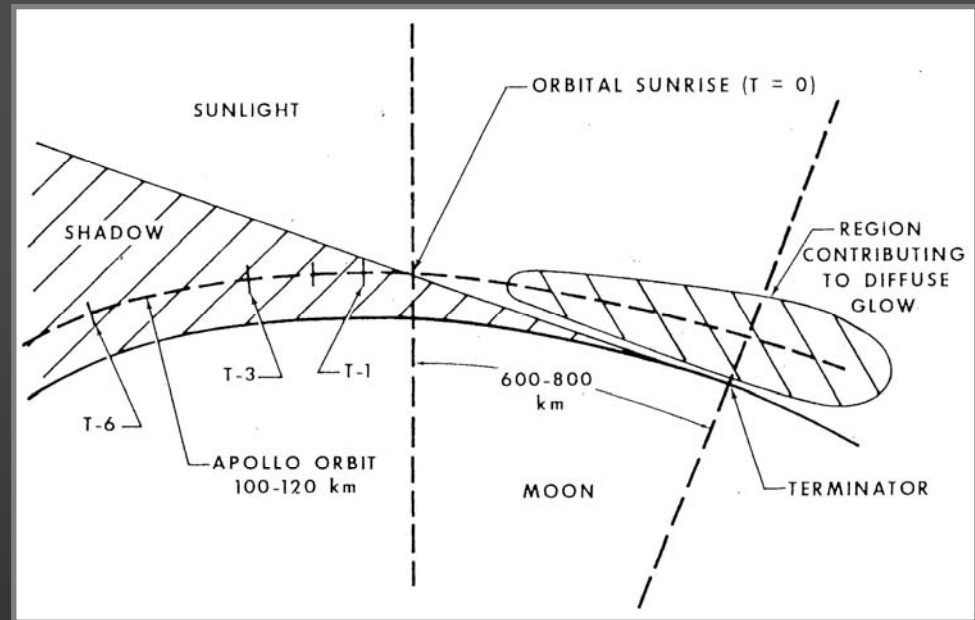
Local Western Horizon

Composite image of morning and evening of local western horizon [Criswell, 1973].

Dust Observed at High Altitudes from Orbit



Gene Cernan sketches
[McCoy and Criswell, 1974].

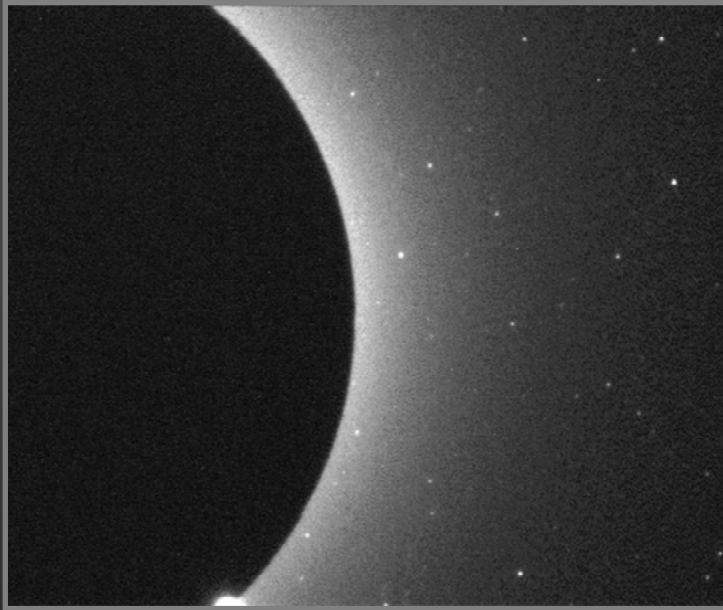


Schematic of situation consistent with Apollo 17 observations [McCoy, 1976].

Lunar dust at high altitudes
(up to ~100 km).

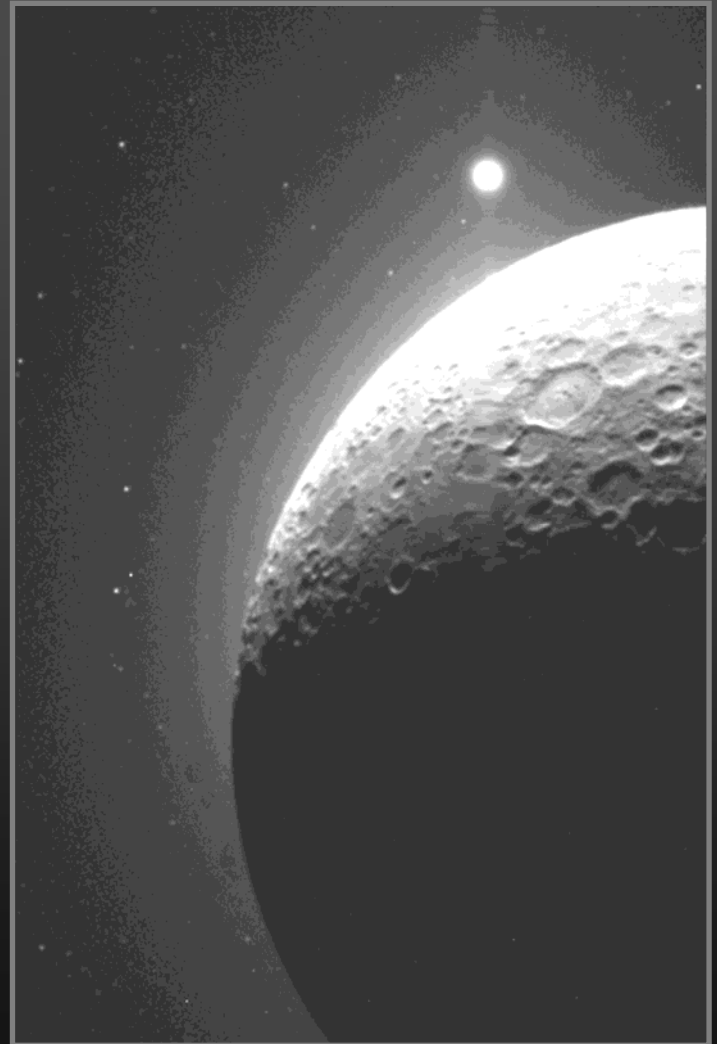
0.1 μm -scale dust present
sporadically (~minutes).

Possible Dusty Horizon Glow seen by Clementine Star Tracker?

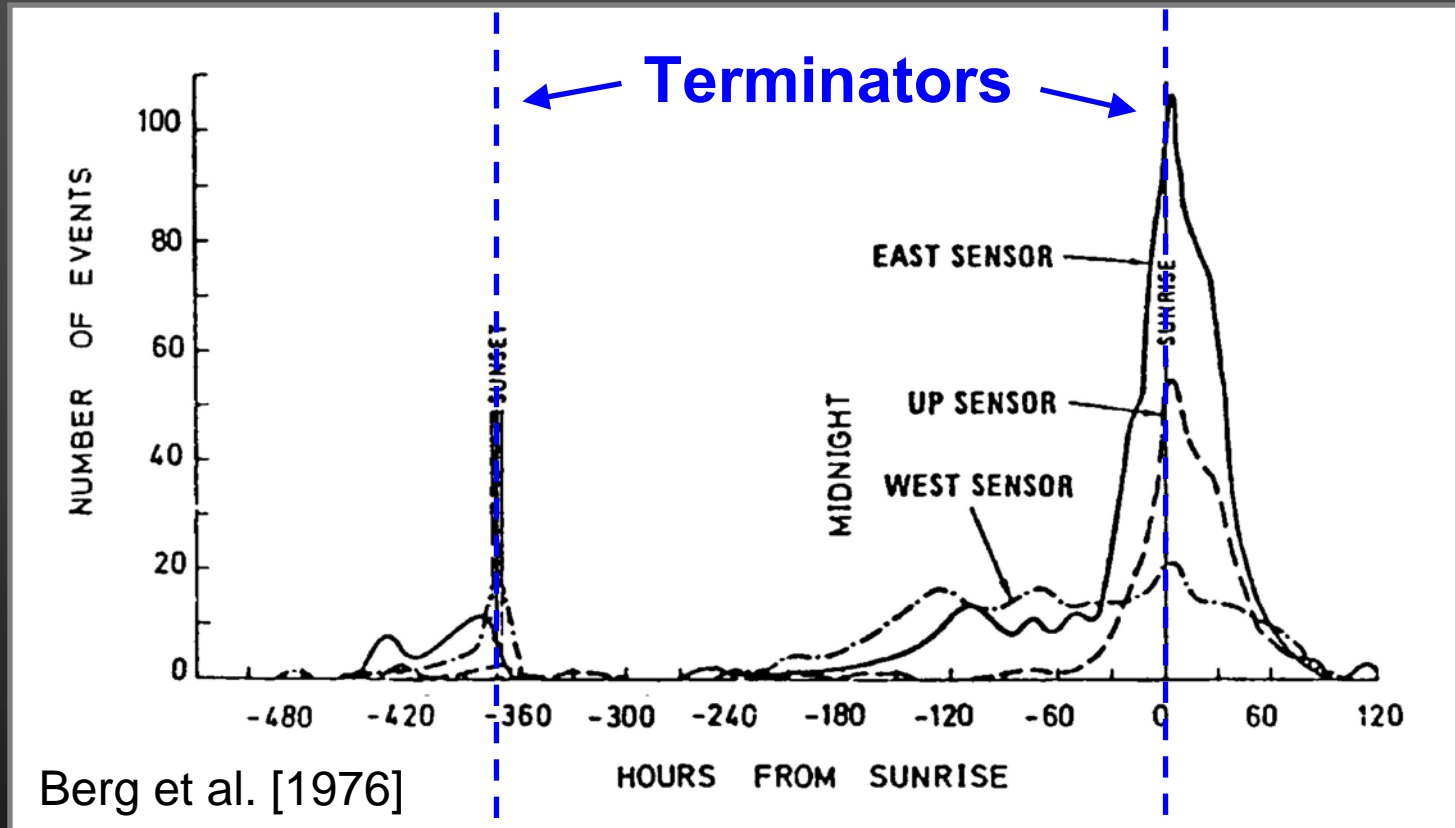


Above: image of possible horizon glow above the lunar surface. The bright crescent Earth partially visible at bottom.

Right: the dark Moon bathed in earth-shine, with a glow above the lunar limb. Venus at top appears larger due to CCD saturation.

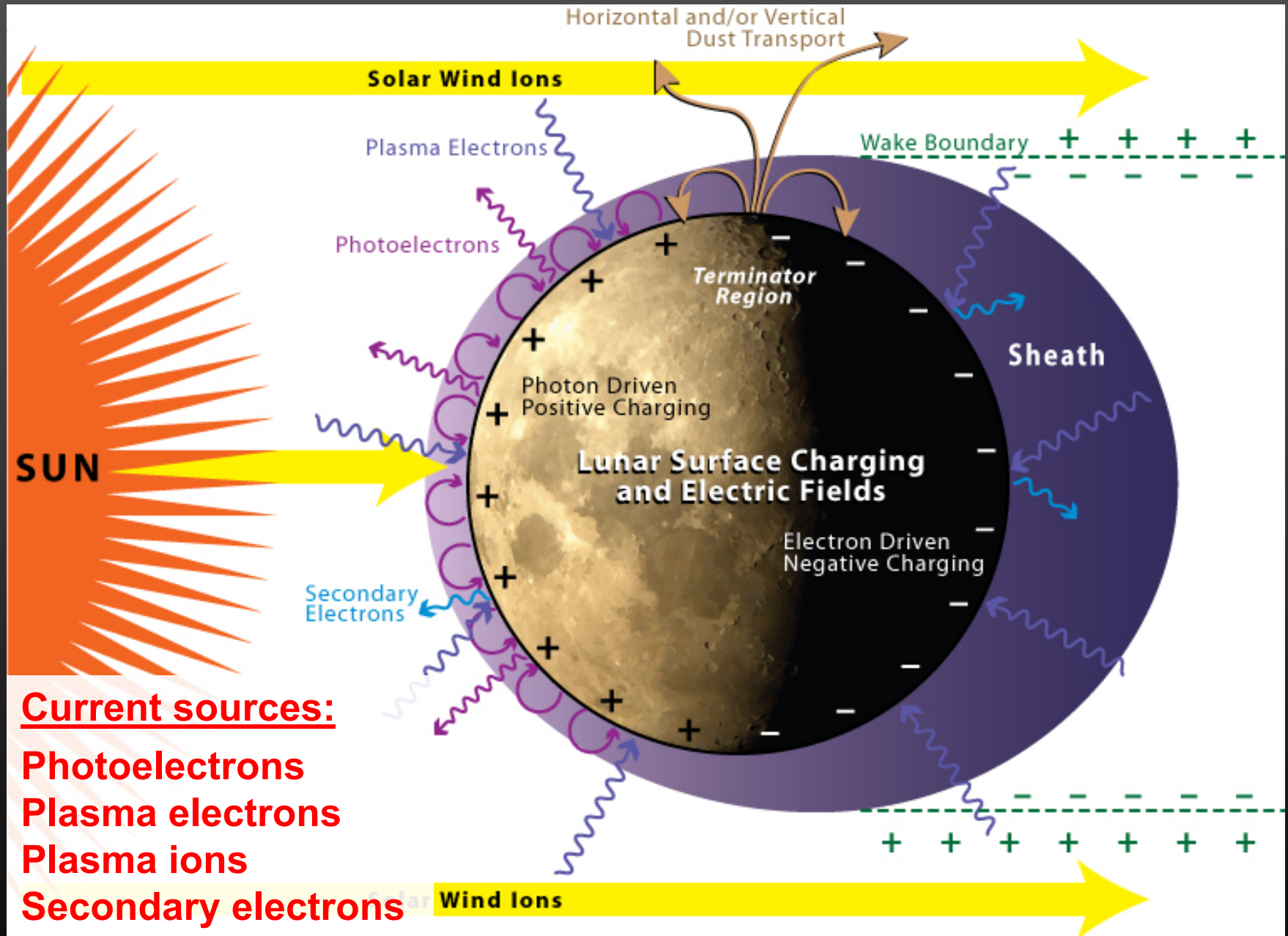


In-Situ Evidence for Electrostatic Dust Transport

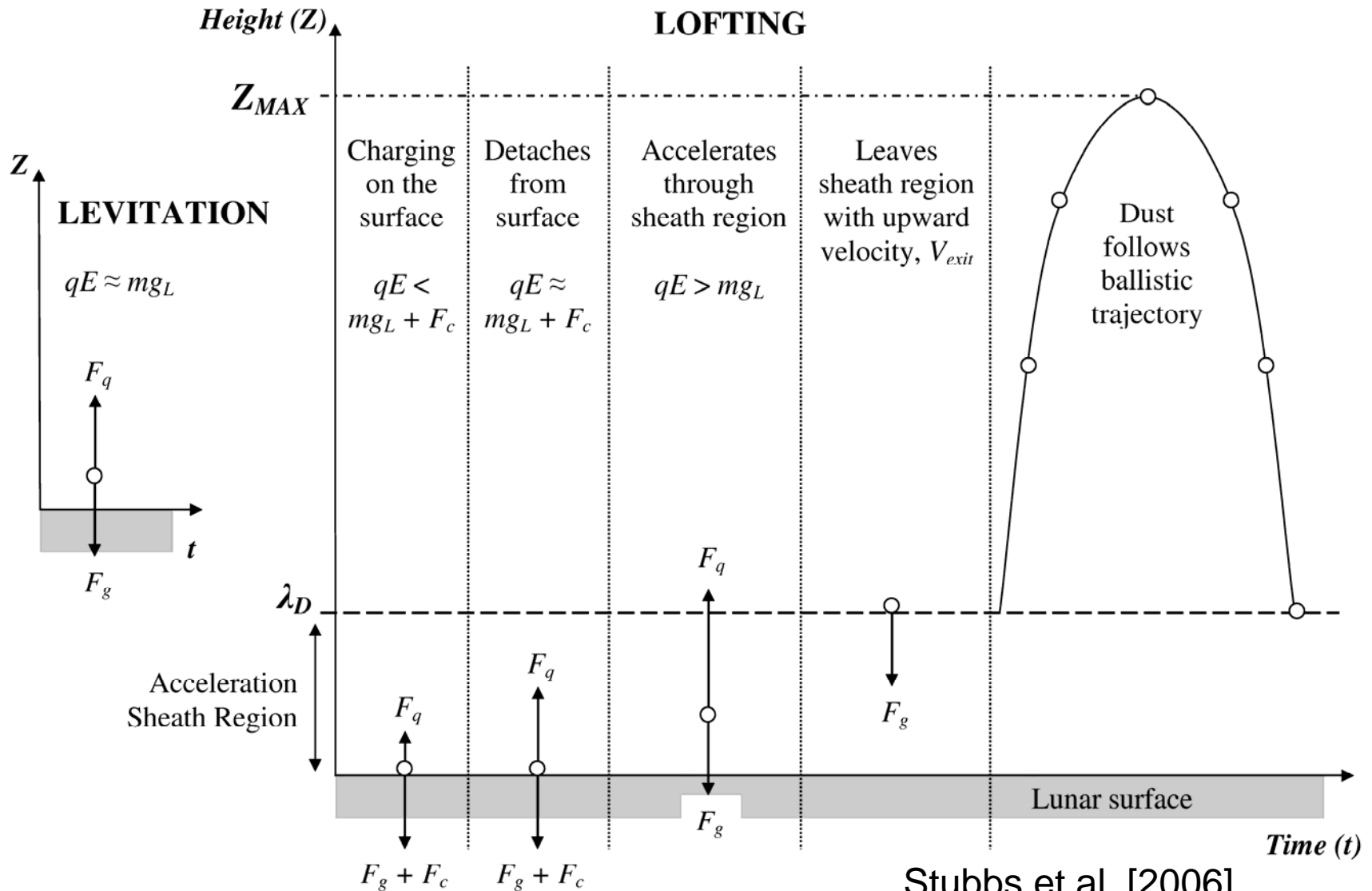


Apollo 17 Lunar Ejecta and Meteorites (LEAM) experiment.

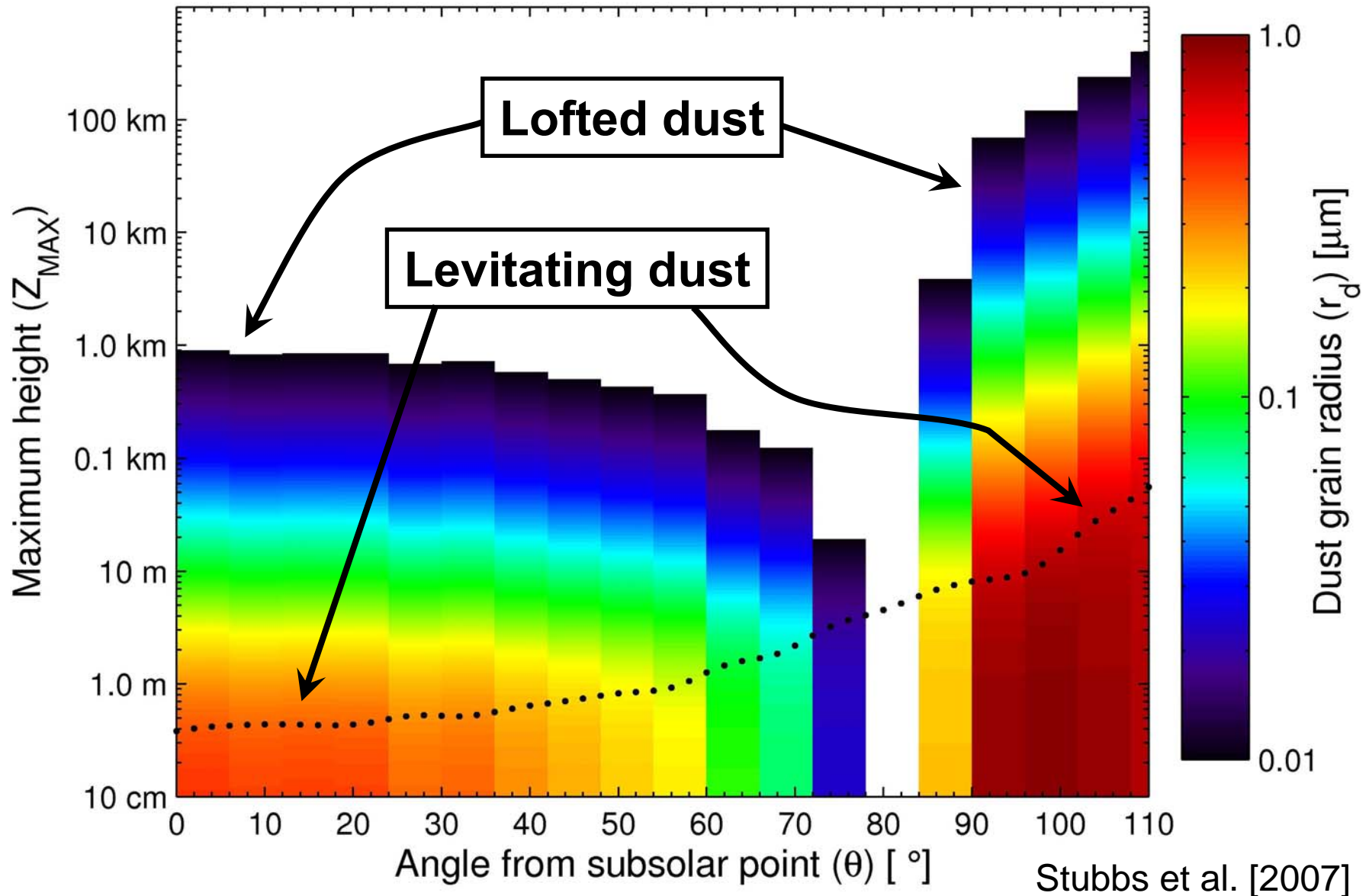
The Lunar Dust-Plasma Environment



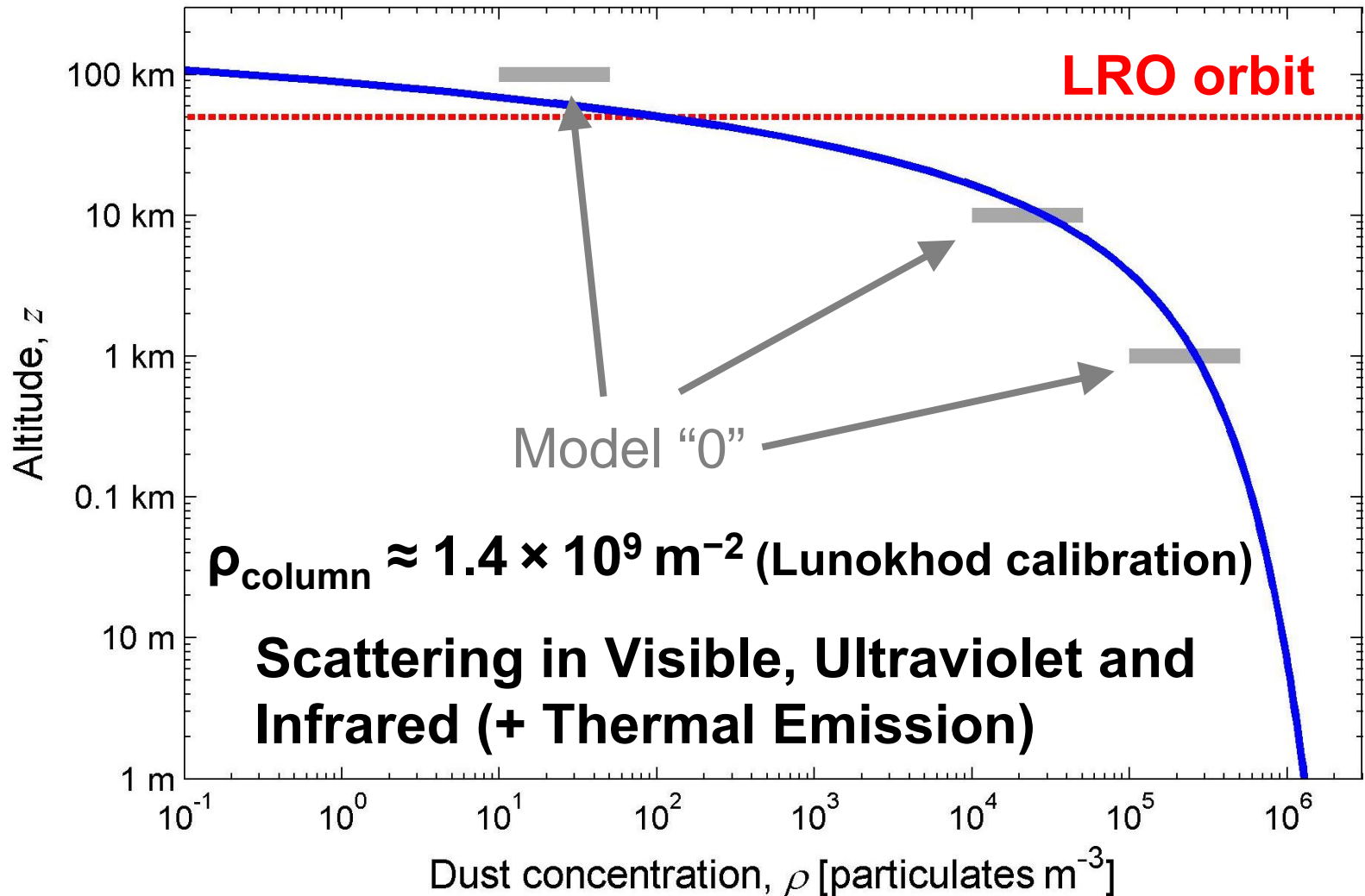
Dynamic Dust “Fountain” Model



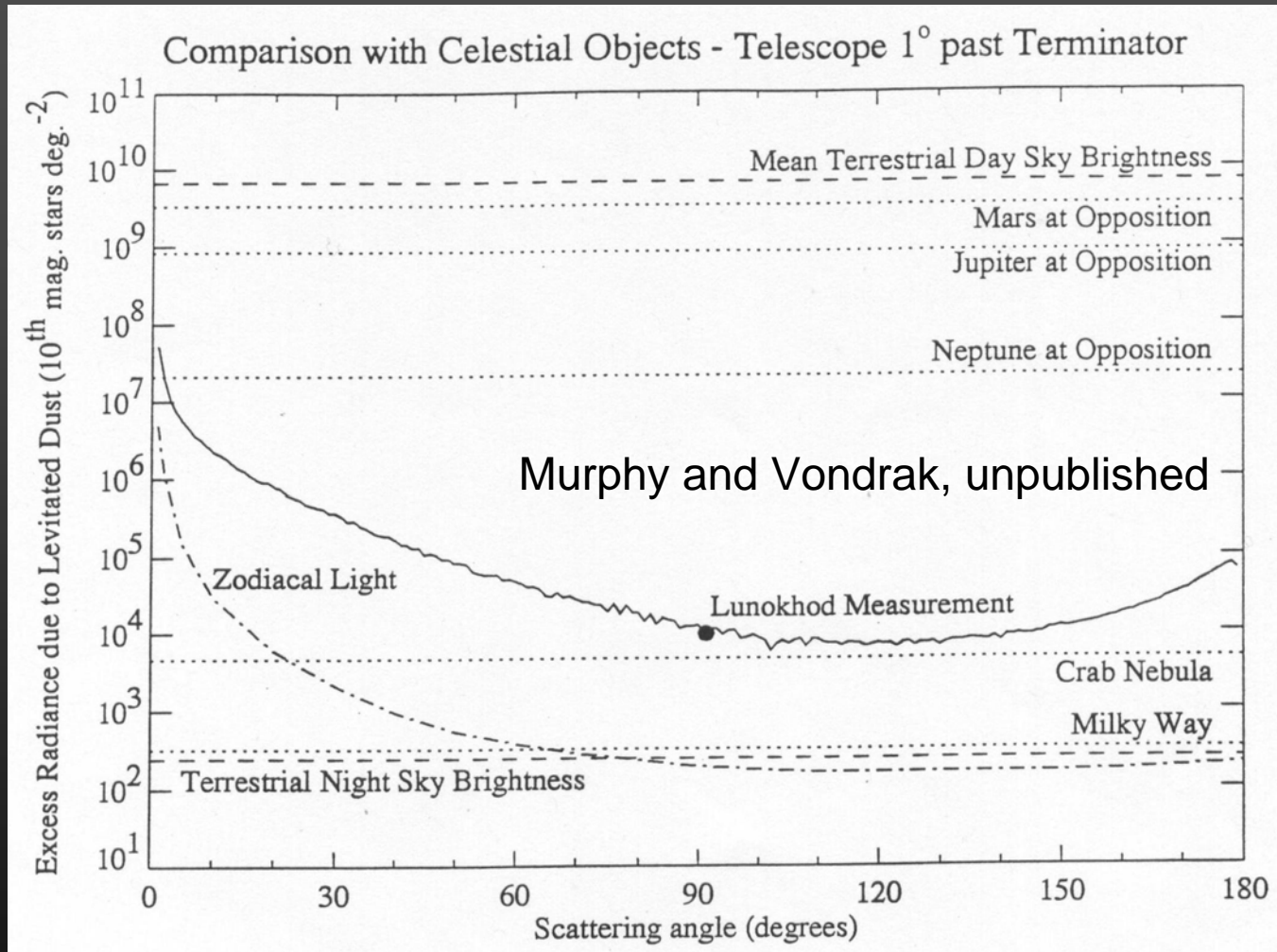
Predictions of Dust Dynamic Fountain Model



Murphy and Vondrak [1993] Model Distribution at the Terminator

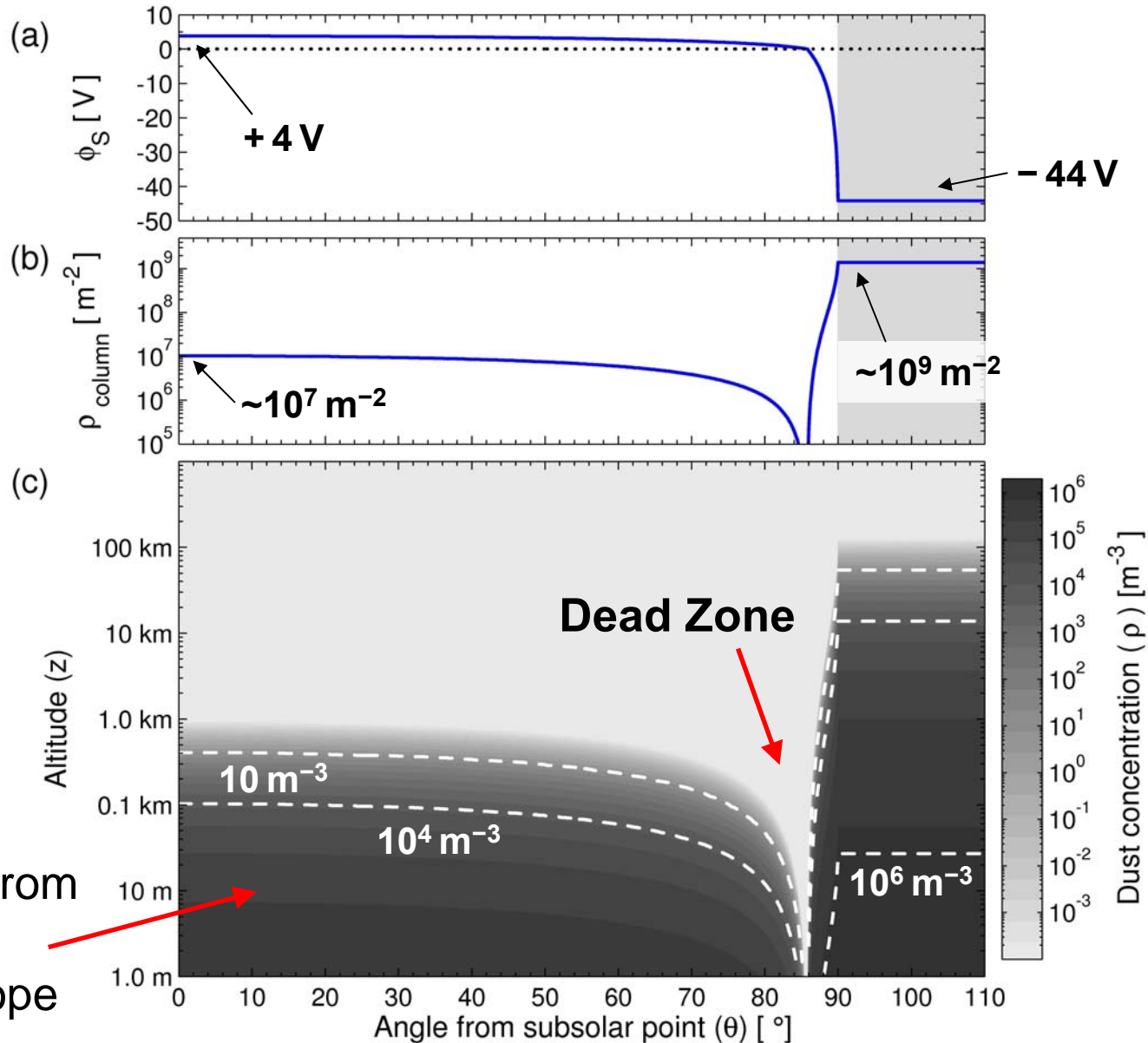


Predicted Sky Brightness in the Visible



UV and IR predicted to be less bright.
Significant IR thermal emissions predicted.

Preliminary Predictions of Dust Concentrations



Evidence from
Apollo 16
UV telescope

Comparative Planetology

Particulates in Solid-Body Exospheres

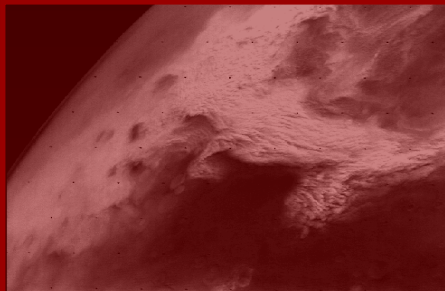
Earth

- Mostly gas, particulates small fraction of mass.
- Particles: Aerosols, dust and ice.
- Active surface-atmosphere interface.
- Many ice-laden thunderstorms driven by local temperature inversions.



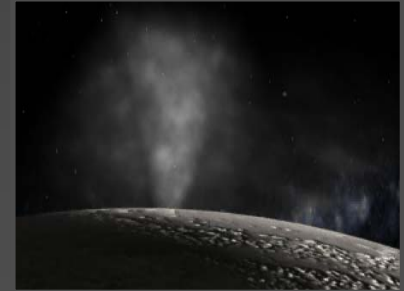
Mars

- Mostly gas, but larger fraction of particulates.
- Particles: Dust aerodynamically lifted from surface.
- Active surface-atmosphere interface.
- Dust storms can trigger a global meteorological instability.

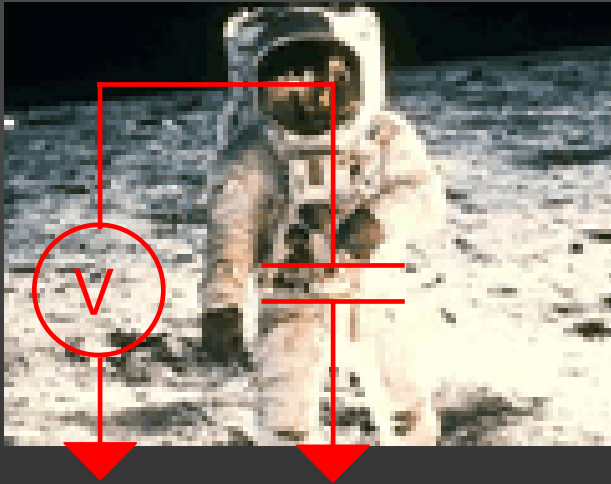


Moon

- “Dusty” Exosphere – particulates dominant mass component?
- Particles: Dust electrostatically lifted from surface (>100 km).
- Active surface-exosphere interface.
- Dust accelerated up to 1 km/s at terminator.



Anthropogenic Dust



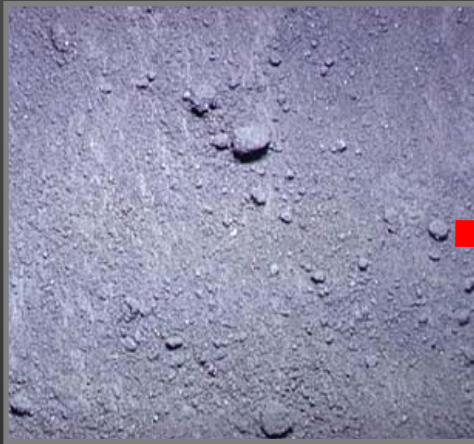
The Human Capacitor

The astronaut is electrically connected to the lunar dust-plasma environment via the voltage sources of the Capacitor-Electrical System

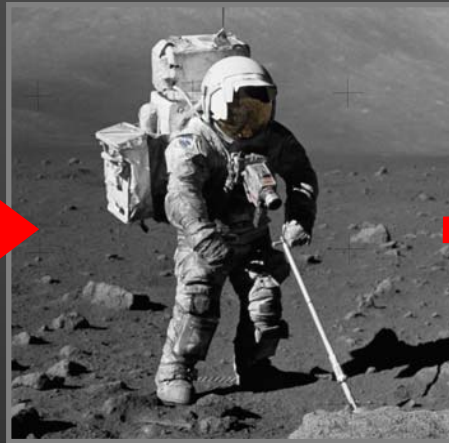
- In addition to “natural” transport, dust will get kicked-up by astronauts.
- Astronauts and equipment moving around on the lunar surface will create & exchange charge via contact electrification – triboelectricity.
- In an “equivalent circuit”, the astronaut can be treated as a “capacitor” which charges as it moves across the lunar surface.
- Input voltages to this capacitor include triboelectric, photoelectric & plasma currents, & induction in high E-field regions.
- These processes will result in the charged dust being attracted toward, and adhering to, the charged astronaut.
- The attached dust will subsequently be carried into the habitat.

Dust From the Surface to the Habitat: What is the “Selection” Process?

Surface Dust Distribution



Dust coated EVA suit



Dust in the Habitat



Probability of dust getting from the surface to the EVA suit depends on:

- Grain size, charge & “perturbation”
- Surface/astronaut electric potential

In turn, this depends on:

- Grain size distribution & composition
- Ambient plasma, illumination & thermal conditions

Probability of dust getting from suit/equipment into the habitat depends on:

- Grain-suit adhesion
- Effectiveness of mitigation efforts

In turn, this depends on:

- Grain shape, composition & charge
- EVA suit material.
- Airlock design

Some Future Necessary *in-situ* Measurements

| Measurement | Instrumentation |
|--|---|
| Dust strikes (dust mass, velocity and charge distributions) | Impact sensor (more sensitive and discriminating than LEAM). |
| Exospheric dust concentrations | Photometer (passive) LIDAR (active) |
| Surface electric potentials | E-fields instrument with boom (and ideally a magnetometer) |
| Plasma characteristics | Electron spectrometers Ion spectrometers |
| Solar Ultraviolet spectrum | Spectrometers and photometers |

Measurements required on the surface (local) and from orbit (global), preferably at the same time.

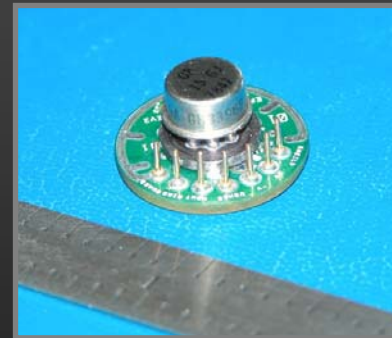
Lunar Emissions, Electrons, and Dust (LEED) Surface Instrument

Objectives:

- Identify the processes that create the dusty exosphere.
- Discover the forces that accelerate charged dust near the terminator.
- Detect the charging of astronauts and equipment in this environment.



RF charged dust detection system, similar to techniques used at the planets [Gurnett, 1983].



DC E-field system with heritage from POLAR and Cluster.



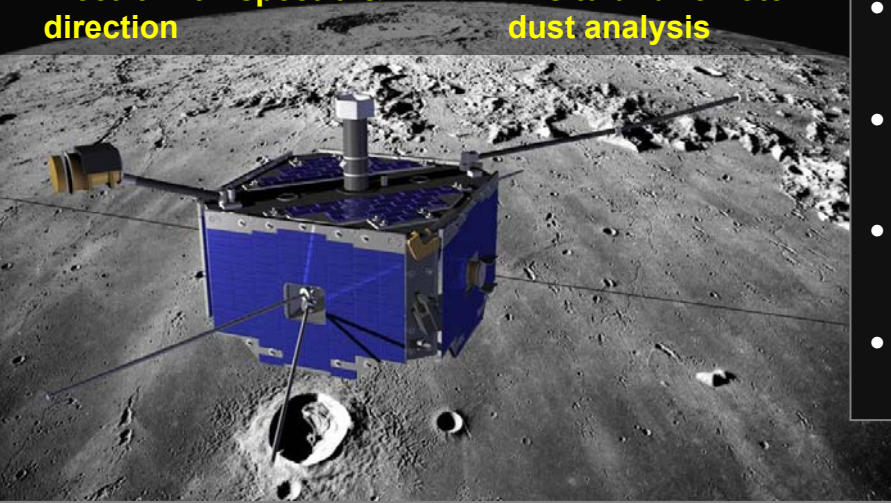
Electron and Ion plasma spectrometers, like those built for Triana.

Patch plate to measure dust adhesion on various materials.

Integrated IDPU to obtain well-correlated high rate data during the most active periods.

Lunar Explorer for Elements And Hazards (LEEAH)

- Magnetic & Electric Fields
- Ion composition
- Electron/ion spectra & direction
- In-situ and remote dust analysis



CUTTING EDGE SCIENCE with PROVEN SYSTEMS

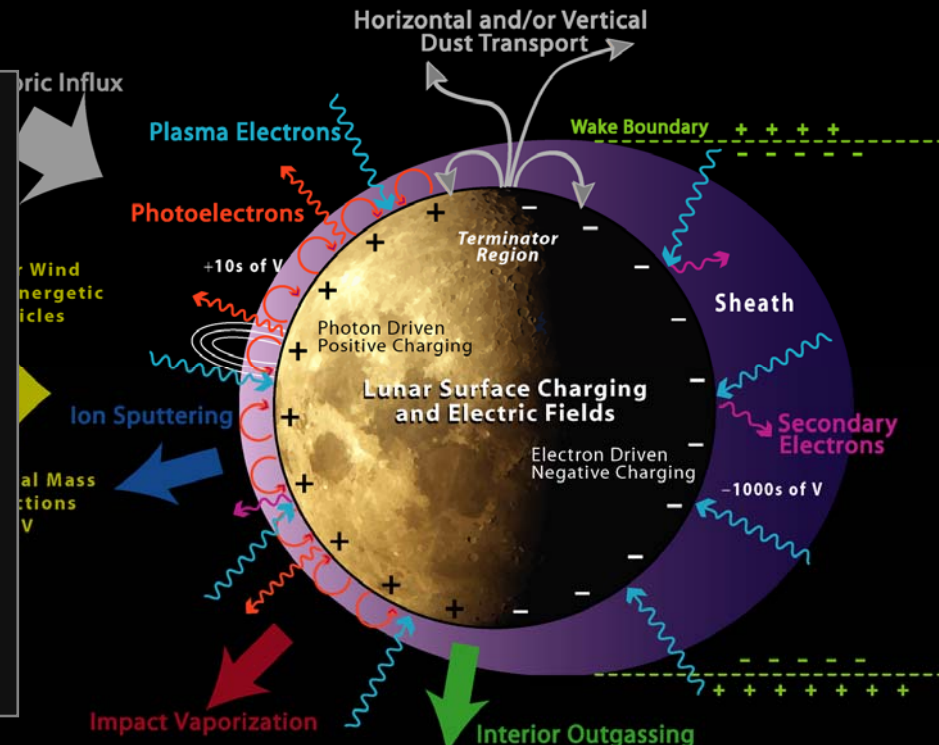
- Finalist for LRO Secondary Payload; funded Phase A development in 2006
- High-heritage instruments and spacecraft (TRL 7-9) from THEMIS & Lunar Prospector
- Science, operations, management teams in place; ~2.25 yr development schedule
- Low cost secondary (<\$60M) or primary (<\$100M) mission options on EELV, Minotaur, Delta-II

SCIENCE

- Lunar surface charging in response to solar and plasma environment
- Dust transport and dusty plasmas/exosphere
- Map surface composition and volatiles
- Fundamental space plasma physics and lunar-solar interactions

EXPLORATION

- Identify resources, including H₂O
- Quantify dust electrification and motion
- Correlate with environmental drivers for prediction and mitigation



Rationale of Timing with Respect to Lunar Exploration

Early Robotic Phase (<2018)

Acquire crucial measurements of the natural environment from orbit and strategic locations on the surface.

Experiments like LEED and missions such as LEEAH should be a priority during this phase.

Early Human Phase (2018 – 2025)

Increase the monitoring of this environment with the greater resources able to be placed on the Moon during this phase.

In particular, study the impact of the enhanced dust transport driven by surface operations, ISRU, etc – the modified environment.

Beyond (>2025)

Deploy large-scale surface network and develop accurate predictive capability (analogous to weather forecasting on the Earth).

Each station in the network could carry a multi-disciplinary payload (e.g., dust sensors, E-field booms, seismometers, etc).

Summary and Conclusions

There is **much compelling evidence** from the Apollo era for the electrostatic transport of lunar dust.

Fundamental Solar System process.

Understanding how astronauts and equipment couple to the lunar dust-plasma environment is crucial.

Important for determining how dust enters the habitat and in what state – how has it been “selected”.

Require **targeted observations** of this environment as soon as possible, in order to develop **effective dust mitigation strategies** for robotic and human exploration.